On-Board Vehicle, Cost Effective Hydrogen Enhancement Technology For Transportation PEM Fuel Cells

- *Contractor*: United Technologies Research Center, East Hartford, CT
- *Subcontractors:* International Fuel Cells, HydrogenSource, Both at South Windsor, CT
- *Point-of-Contact/Principal Investigator*: Dr. Zissis Dardas, Fuel Processing Program Element Leader, Fuel Cells Program, United Technologies Research Center, 411 Silver Lane, MS 129-21, TEL: (860) 610-7371, FAX: (860) 610-7911, Email: dardasz@utrc.utc.com
- *Project Duration*: 38 Months (November 1, 2001-December 31, 2004)
- *Total Estimating Funding*: $2,403,900

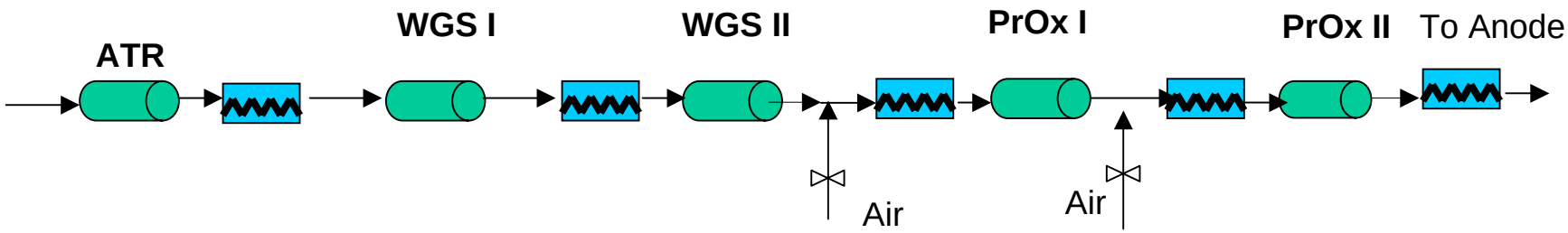
Project Objectives and Technical Goals

- Develop an integrated *Pd-based Membrane Water Gas Shift (WGS) Reactor/Hydrogen Separator Device* Capable Of Producing High Purity Hydrogen From An Integrated Autothermal Reformer for 50 kW PEM Fuel Cell Transportation Power Plants.

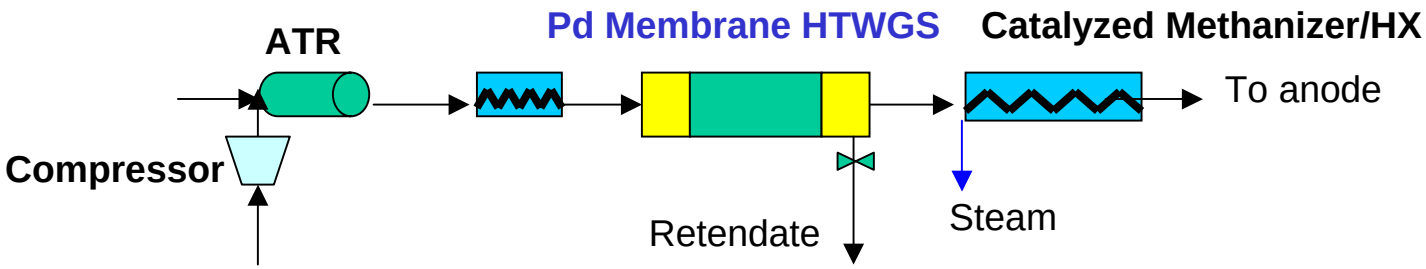
- ***Technical Goals (Compatible to FPS Technical Targets):***
  - *Device Volume*: < 0.35 L/KW (FPS: 0.7 KW/L)
  - *Projected Life (for 1,000 Start Ups/Shut Downs):*10 % Performance Loss for 4,000 hrs
  - *Device Cost:* < $ 12.5/KW (FPS: $25/KW)
  - *Energy Efficiency of Resulting FPS*: 78 %
  - *Cold Start Up*: < 1 min for 33 % of Full Power
  - *Transient Response*: 5 sec from 10 to 90 % Power
  - *Integrated FPS Performance*: < 10 ppm of CO Under Steady State & < 100 ppm Under Transients

Integrated Membrane/Water Gas Shift Reactor

Current Design



Integrated HTWGS/Pd Membrane Reactor



Leads to Compactness and High Purity H_2 instead of Reformate

$CO + H_2O$ === $CO_2 + H_2$ - Shifts the equilibrium towards the H_2 production side

Size and Cost Reduction Rapid Start Up and Faster Dynamic Response due to Mass Reduction through Component Elimination

Desirable Membrane Module Characteristics

- High H_2 permeability for high flux and so, reasonable process economics
  - Very thin Pd alloy layer (<< 10 m), supported on porous metal support (SS, Ni-based alloys)
    - Electroless plating & Uniform Support Particle and Pore Size
  - High differential operating pressure (> 6 atm)
- Very high H_2 separation factor (infinity)
  - Defect-free Pd-alloy layer
- Superior mechanical (for high pressure), thermal (for thermal cycling, start up, shut down) and chemical (for oxidation and corrosion resistance) stability
- Cost Sensitive: very thin layers
- Module easily connected to other process equipment (welding)
- Candidates: Pd, Ru, V, Ta, Ni, SiO_2:
  - *Only Pd alloys combine all previous requirements*
  - *Electroless Plating Process*

Work Plan Summary

Task	Task Name	Owner	Start Date	Finish Date
	Phase I		**11/01/2001**	**04/30/2002**
1	System Analysis	UTRC	11/01/2001	02/28/2002
2	Benefits Analysis	UTRC	01/01/2002	03/31/2002
3	Feasibility Study	UTRC	01/01/2002	04/30/2002
4	Membrane Synthesis-Baseline Properties	UTRC	01/01/2002	04/30/2002
	Phase II		**05/01/2002**	**12/31/2003**
5	Membrane Development, Synthesis & Characterization	UTRC	05/01/2002	12/31/2003
6	Structural Analysis of Membrane Systems	UTRC	05/01/2002	10/31/2003
7	Conceptual Design and Modeling of Membrane Reactor	UTRC	05/01/2002	07/31/2003
8	Small Scale Testing and Performance Evaluation	UTRC	08/01/2002	12/31/2003
	Phase III		**01/01/2004**	**12/31/2004**
9	Fabrication of Prototype Scale Membranes	UTRC	01/01/2004	07/31/2004
10	Functional Design of 50 kWe Membrane Reactor	HyS	01/01/2004	03/31/2004
11	Fabrication of 50 kWe Prototype Hardware		04/01/2004	09/30/2004
11.1	Coordination of Activities	HyS	04/01/2004	09/30/2004
11.2	Construction of Prototype Hardware	IFC	04/01/2004	09/30/2004
12	Testing and Evaluation of Prototype Hardware		10/01/2004	12/31/2004
12.1	Coordination of Activities & Performance Evaluation	HyS	10/01/2004	12/31/2004
12.2	Testing	IFC	10/01/2004	12/31/2004
	Project Management and Documentation			
13	Management	UTRC	11/01/2001	12/31/2004
14	Reporting	UTRC	11/01/2001	12/31/2004

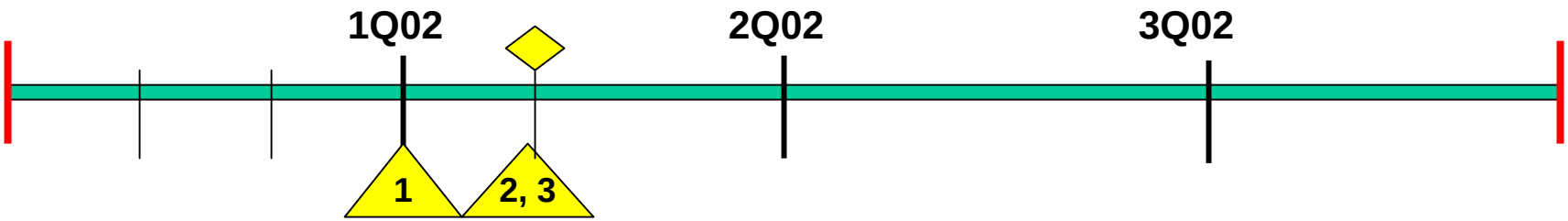
Key Milestones

1) Demonstrate a Parametric Analysis for Device and Integrated FPS Volume, Cost and Efficiency as a Function of Membrane Thickness, Membrane Area and Differential Pressure.

2) Quantify Benefits of Proposed Concept using System Steady State and Dynamic Models Toward FPS Volume, Weight, Cost, Performance, Start Up & Transient Response vs.. Baseline FPS

3) Demonstrate Pd Membrane Synthesis Process Capability to 11 microns Pd Layer Thickness on a S.S. Support

Go-No-Go Decision Point: (◆): Proposed System Projected Technical Targets Surpass Baseline FPS at least 30 % of the size.



Key Milestones

1) Demonstrate finite element structural models that evaluate stress distribution in the membrane composite system during thermal cycling, start up and shut down (**10/31/02)**

2) Demonstrate synthesis of a 5 micron thick Pd-Ag alloy membrane on a 6 " long, 1 " diameter SS tube **(03/31/03)**

3) Demonstrate a mathematical model for the design of the membrane device, validated to +- 10 % on a 0.5 KW WGS membrane reactor **(06/30/03)**

4) Demonstrate < 1 % performance loss for 400 hrs of operation with 100 start up/shut down cycles for the WGS reaction of the optimum 5 microns thick, 6" long membrane **(07/31/03)**

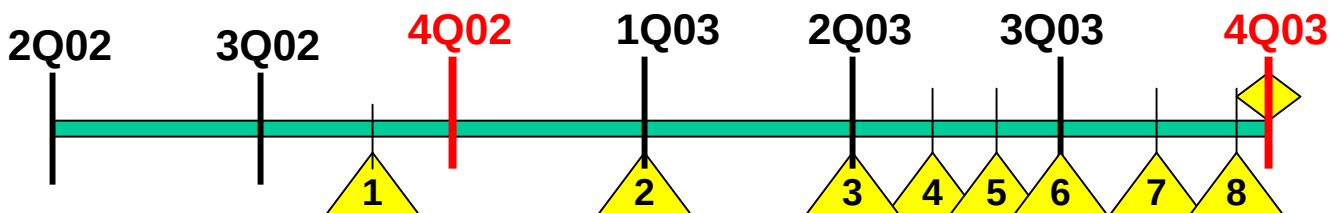
5) Demonstrate synthesis of 1 micron thick Pd-Ag alloy membrane on a 6 " long, 1 " diameter SS tube **(08/31/03)**

6) Demonstrate a mathematical model to extrapolate membrane performance from experimental data at 200 hrs and 50 start up/shut down cycles. Validate model to +-10 % from experimental data at 400 hrs & 100 cycles **(09/30/03)**

7) Demonstrate an optimum membrane with 90 % H_2 recovery and < 1 % performance loss for 400 hrs of operation with 100 start up/shut down cycles for the WGS reaction of the optimum 5 microns 6" long membrane **(11/15/03)**

8) Demonstrate 50 kW device simulated performance during system start up, and under steady steady and transient conditions under optimum process conditions (**12/15/03)**

Go-No-Go Decision (◇): At least 30 % projected improved volume, and at least equivalent projected life, cost, start up time, transient response time and performance relative to the Baseline FPS **(12/31/03)**



Key Milestones

1) Demonstrate blue prints of 50 KW WGS Membrane Reactor **(03/31/04)**

2) Demonstrate required amount of Pd-Ag alloy membrane tubes for the 50 KW prototype WGS reactor **(07/31/04)**

3) Demonstrate an integrated 50 KW prototype WGS membrane reactor **(09/30/04)**

4) Demonstrate > 90 % H_2 recovery & (estimated) 78 % FPS efficiency, < 1 % performance loss for 400 hrs of operation with 100 start up/shut down cycles for the 50 KW prototype WGS membrane reactor using sulfur-free simulated reformate (12/15/04)

5) Shipment of 50 KW prototype membrane reactor to DOE for third-party testing and evaluation **(12/30/04)**